Lime Response as Related to Percent Al Saturation, Solution Al, and Organic Matter Content[1]

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ABSTRACT

Concentration of soil solution Al in mineral soils was related to the percent Al saturation of the effective CEC. In organic soils, however, the concentration of Al in the soil solution was more related to the amount of exchangeable Al than to percent Al saturation. Soils with increasing organic matter content had a lower content of soil solution Al at a given pH.

Liming increased the growth of corn on mineral soils when the Al saturation was greater than 70%. On all soils except one, corn responded to liming when the concentration of soil solution Al was greater than 0.40 meq/liter. Soybeans responded to liming on mineral soils when the Al saturation was greater than 30%. On all soils soybeans responded to liming when the concentration of soil solution Al was greater than 0.20 meq/liter.

Additional Key Words for Indexing: corn, soybeans, soil solution, exchangeable Al.

ALUMINUM is a major component of most inorganic soils and when released in weathering processes undergoes hydrolysis with a resultant increase in soil acidity through release of protons (8, 15). In addition to being a source of soil acidity, Al is also a toxic element to some plants in acid soils. It has been demonstrated that plants are differentially tolerant to given concentrations of Al (6). Root growth is limited by toxic quantities of Al and the limited root system may reduce uptake of water as well as nutrients thus reducing top growth. The detrimental effect of soil solution Al on cotton root elongation has been reported by Adams and Lund (1).

Organic matter apparently has some influence on the availability of Al since plants grow more satisfactorily on organic soils at a considerably lower pH than on mineral soils. This is true even though total Al is quite high in some organic soils. The strength of bonding or the complexing of Al may result in less Al in the soil solution. It has been suggested by Jackson (8) that monomers of Al are readily exchangeable while dimers and polymers are not. Coleman et al. (5) and Lin and Coleman (10) displaced cations in some mineral soils with unbuffered 1*N* KCl, summed the cations, including Al, and called this the "permanent charge" CEC. The variable charge fraction of the CEC may have been occupied by less easily displaceable Al compounds. McLean et al. (11), working with soils varying in organic matter up to about 10%, attributed the variable charge of soils to the organic fraction.

Carboxyl groups of organic matter are the primary functional groups involved in exchange reactions with cations. Using infrared techniques, Schnitzer and Skinner (14) found that Al would react with organic matter up to a 6:1 molar ratio indicating six carboxyl groups per organic matter molecule. It is possible that Al could be electrostatically bound to one or more carboxyl groups depending on the degree of polymerization and effective charge of the Al molecule. Clark and Nichol (4) suggested the formation of insoluble Al organic matter complexes. It is possible that organic matter reduces the solubility of Al through complex formation and results in less Al in the soil solution. This may be one reason why plants grow well at a lower pH on organic soils than on mineral soils. Clark and Nichol (4) suggest that it may be necessary to take into account both the pH and the solubility of Al in estimating the liming needs of organic soils.

It is not known to what degree organic matter influences the Al in soil solutions, and thus plant growth. The purpose of this study was to observe the effect of organic matter on chemical exchange characteristics, soil solution composition, and response of plants to liming.

MATERIALS AND METHODS

Soils of the coastal plain of North Carolina varying in organic matter were selected for this study. Topsoils from cultivated areas were used. Soils with 2.0, 2.7, and 4.0% organic matter shall be referred to as mineral soils while those with 25, 52, and 68% organic matter shall be referred to as organic soils. Easily oxidizable organic matter was determined on the mineral soils by a modification of the Walkley-Black method used by the Soil Testing Laboratory (16). For the organic soils, organic matter was determined by oxidation with H_2O_2. Exchangeable Ca, Mg, Al, and H were extracted with unbuffered 1*N* KCL solution. Ten grams of soil were shaken with 50 ml of solution for 30 min, leached with gentle suction by a Buchner filtering apparatus and washed with an additional 50 ml of solution. This was repeated four times for mineral soils and seven times for organic soils. Calcium and Mg were determined by atomic absorption spectrometry, H and Al were determined by titration with 0.1*N* NaOH using methyl orange and phenolphtalein indicators. The total sum of exchangeable cations was considered as the cation exchange capacity.

Using the values for exchangeable acidity (H + Al), $Ca(OH)_2$ was added to soil samples to neutralize a theoretical 0, 12.5, 25, 50, 75, 100, 200, and 300% of the exchangeable acidity. Three wet-dry-mix cycles over a period of 10 days were completed and samples were incubated moist for an additional 2 weeks. Exchangeable Ca, Mg, Al, and H were determined by the above procedure. When the soil was at field capacity soil solutions were displaced by a modification of the method of Burd and Martin (3) using chromatograph tubes. The soil solution Ca and Mg were determined by atomic absorption spectrometry and Al colorimetrically by the Alizarin Red-S method of Parker and Goddard (13).

Certain rates of lime used in the incubation study were selected for a greenhouse experiment using corn (*Zea mays*

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L.) and soybeans (*Glycine max* L.) as test crops. Two kilos of the mineral soils and one kilo of organic soils were used. The $Ca(OH)_2$ was added to soil spread in a thin layer and three wet-dry-mix cycles were completed to facilitate reaction and assure uniformity. Soils were fertilized with P, K, and Mg according to individual soil tests; these fertilizers were added after the third mix cycle. Twenty-five milliliters of Hoaglands (7) strength solution of Zn, Cu, Mn, and B were added to each pot. Ammonium nitrate at the rate of 0.12 g per pot was added at weekly intervals to each pot in which corn was growing. Two corn and four soybean plants per pot were grown. Soybean seed received a commercial inoculant and Mo before planting. Corn plants were harvested after 5 weeks and soybeans after 7 weeks; plant tops were dried at 70C and weighed. Experimental design was randomized block with three replications of each treatment.

RESULTS AND DISCUSSION

Factors Affecting Soil Solution Al

The initial chemical properties of the soils used in this study are given in Table 1. The relationship between soil solution Al and pH for soils varying in organic matter is presented in Fig. 1. As the organic matter content of soils increases, there is less Al in the soil solution at a given pH. This can be attributed to the complexing of Al by organic matter and reducing the amount of Al in the soil solution. There is only one exception to this relationship, namely, organic 1 which had 25% organic matter. The mineral fraction for this soil was mainly fine sand and the effective influence of organic matter may have been greater than that for other organic soils. Small increments of lime resulted in relatively rapid decreases in soil solution Al for all soils. However, some Al was measured at the highest rate of liming. The fact that Al was measured above pH 5.5 is not consistent with work involving subsoils. The presence

Table 1—Initial chemical properties of the soils

Soil	% OM	pH	Exchangeable Ca	Mg	Al	H	Soil solution Al	Ca
			meq/100 g				meq/liter	
Norfolk	2.0	4.9	0.06	0.02	1.43	0	0.55	0.75
Rains	2.7	4.7	0.11	0.02	1.62	0	0.53	5.00
Dunbar	4.0	4.6	1.00	0.11	3.67	0	0.54	4.30
Organic 1	25.0	3.7	5.62	1.46	5.69	5.25	0.28	3.50
Organic 2	68.0	4.2	19.50	10.16	6.51	3.95	0.39	4.81
Organic 3	52.0	4.2	11.50	7.08	14.06	4.80	0.46	3.75

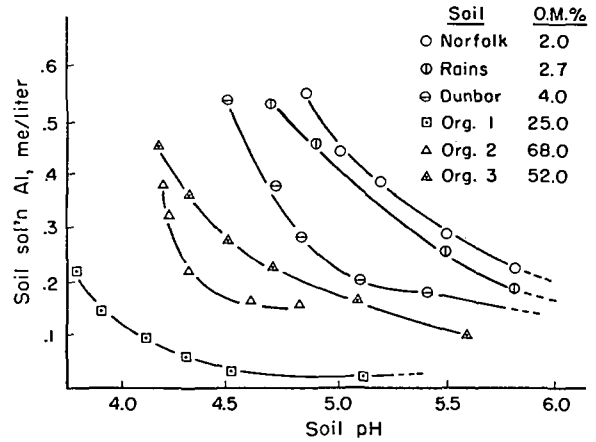

Fig. 1—Effect of organic matter on the soil solution Al-pH relationship.

Table 2—Growth of corn with different rates of lime

Soil	Theoretical % acidity neutralized with lime rates used* 0	12.5	25	50	75	100	200	300
	g/pot							
Norfolk	3.17 a	4.15 abc	4.37 bc	3.18 a	4.50 c	3.45 ab		
Rains	4.72 a	5.87 b	6.30 bc	6.68 bc	7.13 c		4.65 a	
Dunbar	3.12 a	3.21 a	2.72 a	3.27 a	3.49 a		3.57 a	
Organic 1	3.78 a		6.07 b	8.59 c	9.87 d	9.73 d	10.47 d	
Organic 2	6.06 a		6.18 a		6.11 a	5.99 a	6.01 a	5.85 a
Organic 3	5.32 b		7.56 c		7.77 c	7.68 c	5.47 b	3.49 a

* Values with the same letter for each soil are not significantly different at the 0.05 level.

of higher contents of organic matter and/or fertilizer salts in these fertilized topsoils may have influenced the results.

The relationship between soil solution Al and percent Al saturation for the mineral and organic soils is shown in Fig. 2. The concentration of Al in the soil solution of mineral soils is determined by the percent saturation of the effective CEC with exchangeable Al. All mineral soils behaved similarly and one line appeared to satisfactorily characterize that relationship. At about 60 to 70% Al saturation there was a relatively sharp change in slope of the curve with large increases in soil solution Al as percent Al saturation increased above 70%. These results agree quite well with those of Nye et al. (11) in which they report low concentrations of soil solution Al in soils of small electrolyte concentration when Al saturation is below about 60%.

With the organic soils there was no general relationship between percent Al saturation and the amount of Al in the soil solution such as was found with the mineral soils. For organic soils, small changes in percent Al saturation resulted in large changes in soil solution Al. The lines are almost linear and do not show a sharp break at a given point as was the case for mineral soils. The data suggest that for organic soils, the amount of exchangeable Al rather than the percent saturation is more important in determining the amount of Al in the soil solution.

Plant Growth as Related to Al

The yield of corn as influenced by liming to neutralize various theoretical amounts of exchangeable acidity is presented in Table 2. Lime rates were used which would give

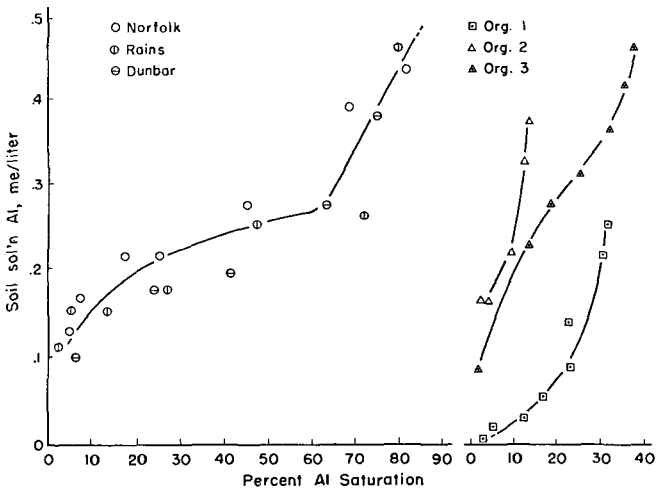

Fig. 2—Relationship between percent Al saturation and soil solution Al.

Table 3—Soil pH resulting from lime additions to theoretically neutralize various amounts of exchangeable acidity

Soil	Theoretical % neutralization of soil acidity							
	0	12.5	25	50	75	100	200	300
	pH							
Norfolk	4.9	5.0	5.3	5.5	5.8	6.1	6.9	7.8
Rains	4.7	4.9	5.0	5.6	5.8	6.1	6.8	7.7
Dunbar	4.6	4.7	4.8	5.1	5.4	5.7	6.6	7.6
Organic 1	3.7	3.8	3.9	4.1	4.3	4.5	5.1	5.8
Organic 2	4.2	4.2	4.2	4.3	4.3	4.4	4.6	4.9
Organic 3	4.2	4.3	4.3	4.4	4.5	4.7	5.1	5.6

solution Al concentrations throughout the range of the steep portion of the curves shown in Fig. 1. The pH values obtained with the various liming rates are given in Table 3. In most instances a wide range of pH values was obtained. The plant growth data indicates that obvious "overliming" did occur at the high rates for some of the soils as reflected by decreased growth. There were significant responses to liming for four of the soils and no response to liming for two soils. The significant growth ranges according to Duncan's multiple range test indicate that for the soils responding to lime there was a first positive response, a range of peak yields, and then a decrease in yield with additional increments of lime. The decrease in growth to higher increments of lime was apparently a result of nutrient imbalance. Growth of corn for all treatments on the Dunbar soil was low, with no response, and is unexplained.

The soil properties at which maximum growth of corn was obtained are given in Table 4. Corn responded to liming in mineral soils only when the soils were more than 70% Al saturated except on the Dunbar where some other factor probably limited growth. For organic soils the growth response broke at 18% Al saturation for organic 1 and 32% for organic 3. Organic 2 soil had an Al saturation of only 16% for the check treatment and gave no response. Organic 3 soil had more clay than other similar soils and this may explain why the growth response broke at a higher Al saturation.

Maximum growth of corn was obtained when the concentration of soil solution Al was less than 0.40 meq/liter except on organic 1 where a much lower level was required (Fig. 3). However, the initial pH of organic 1 was 3.7 and did not go above 4.0 until lime rates were applied which theoretically neutralized more than 50% of the exchangeable acidity (Table 3). Thus it is hypothesized that the poor growth on organic 1 was due to the H ion concentration rather than the soil solution Al.

For mineral soils there is a good agreement between the Al saturation at which maximum growth of corn was obtained and the relationship between percent Al saturation and Al in the soil solution. Maximum growth was obtained at about 60 to 70% Al saturation, the point at

Table 4—Soil properties at which maximum growth of corn was obtained

Soil	pH	% Al saturation	Exch. Al	Soil solution Al	Exch. Ca	Soil solution Ca
			meq/100 g	meq/liter	meq/100 g	meq/liter
Norfolk	5.3	70	1.12	0.39	0.47	1.88
Rains	5.0	73	1.25	0.27	0.44	7.00
Organic 1	4.3	18	3.70	0.06	13.88	8.00
Organic 3	4.3	32	11.72	0.37	15.00	4.00
			No response to lime			
Dunbar	4.6	77	3.67	0.54	1.00	4.30
Organic 2	4.2	16	6.51	0.39	19.50	4.81

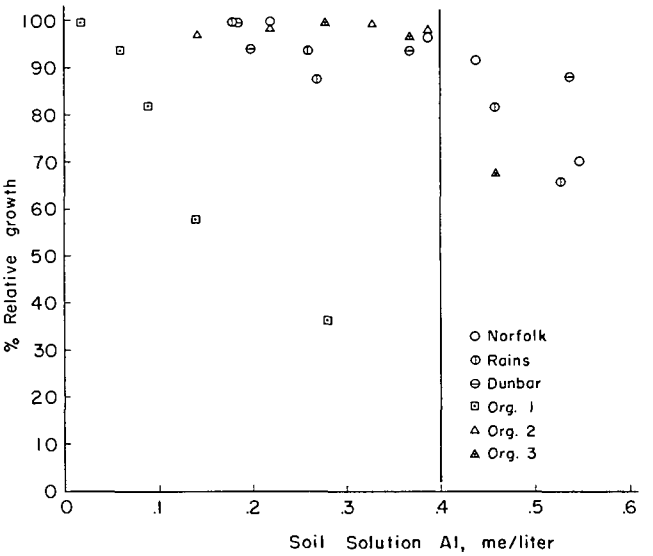

Fig. 3—Relative growth of corn as related to concentration of soil solution Al.

which there was a marked decrease in the amount of Al in the soil solution.

The growth of soybeans as influenced by liming on five of the soils is given in Table 5. In four of the soils a response to liming occurred. Duncan's multiple range test indicated three levels of growth for all soils in which a response occurred. In contrast to the type response obtained for corn there was not a reduction in growth at the highest lime rates. Also, there was less variation in growth among soils for soybeans.

Soil chemical properties at which maximum growth of soybeans was obtained are presented in Table 6. Soybeans responded to a higher rate of liming than did corn and required a lower concentration of soil solution Al for maximum growth. For maximum growth of soybeans the soil solution Al should be less than 0.20 meq/liter (Fig. 4). With mineral soils the exchangeable Al saturation

Table 5—Growth of soybeans with different rates of lime

Soil	Theoretical % acidity neutralized with lime rates used*							
	0	12.5	24	50	75	100	200	300
	g/pot							
Norfolk	5.44 a	8.89 b	9.48 bc	10.72 bc	11.95 c	10.69 bc		
Rains	8.51 ab	8.25 a	10.60 abc	13.34 c	12.62 bc		11.83 c	
Dunbar	7.19 a	7.64 ab	9.68 abc	9.61 abc	11.05 c		10.45 bc	
Organic 2	6.50 a		7.45 ab		9.45 b	8.79 ab	12.87 c	14.47 c
Organic 3	9.26 a		9.69 a		11.83 a	10.39 a	10.43 a	11.45 a

* Values with the same letter for each soil are not significantly different at the 0.05 level.

Table 6—Soil properties at which maximum growth of soybeans was obtained

Soil	pH	% Al saturation	Exch. Al	Soil solution Al	Exch. Ca	Soil solution Ca
			meq/100 g	meq/liter	meq/100 g	meq/liter
Norfolk	5.8	27	0.48	0.22	1.29	4.00
Rains	5.6	49	0.80	0.26	0.82	8.00
Dunbar	5.4	26	1.30	0.18	3.56	9.75
Organic 2	4.6	05	3.44	0.17	34.25	7.28
Organic 3	4.5	18	7.80	0.28	26.15	5.42

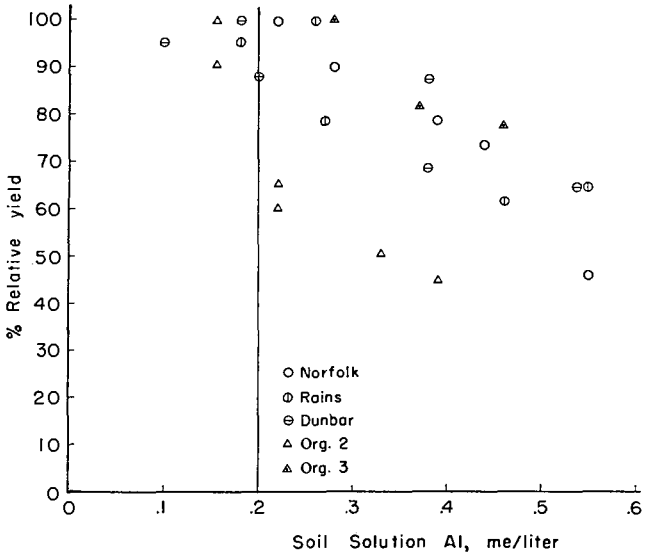

Fig. 4— Relative growth of soybeans as related to concentration of soil solution Al.

should be less than 30% in order that the concentration of soil solution is low enough that it does not limit growth.

For all of the soils there was not a consistent relationship between pH or exchangeable Al and the response of corn and soybeans to liming. These values varied for the different soils at the point of maximum response especially among soils with large differences in organic matter.

The most consistent measurement in terms of response to liming was in the soil solution Al. The response could be related somewhat consistently to soil solution Al in both mineral and organic soils and values were similar at maximum growth irrespective of variations in soil organic matter.

Ca Content of the Tissue

The Ca concentrations of the corn and soybeans for the no lime treatment and the treatment resulting in maximum growth are given in Table 7. Calcium concentration of corn at optimum growth was in the range of 0.47 to 0.66%. The Ca concentration of soybeans at optimum growth varied from 0.86 to 1.07%.

The Ca concentrations of the unlimed soils, except for the Norfolk, were in the range indicated to be adequate for plant growth (2). The poor growth of the plants on the unlimed soils was therefore not due to a lack of Ca but rather to the detrimental effect of Al on absorption and translocation of Ca (9).

Table 7—The percent Ca of whole plants of corn and soybeans on the unlimed soils and on the limed soils at maximum growth

Soil	Corn		Soybeans	
	Check	Maximum growth	Check	Maximum growth
	% Ca		% Ca	
Norfolk	0.28	0.53	0.39	0.86
Rains	0.40	0.66	0.47	1.04
Dunbar	0.39	--	0.46	1.05
Organic 1	0.32	0.59	--	--
Organic 2	0.46	--	0.62	1.07
Organic 3	0.39	0.47	0.47	0.95

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